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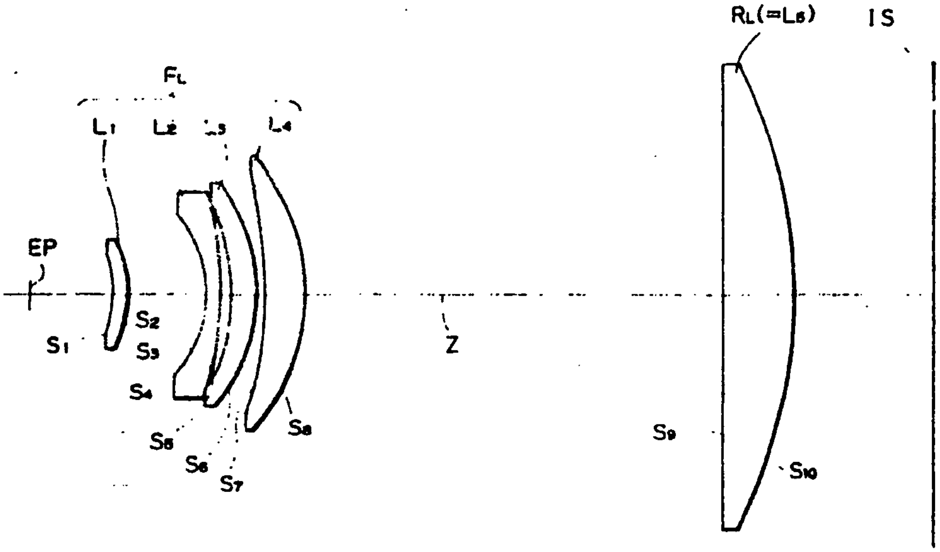
(54) Telecentric f-theta lens system.

(57) The present invention is directed to a telecentric f-θ lens system, the telecentric f-θ lens system comprises; a first lens group having an entrance pupil, which inicudes a first lens in the form of meniscus having a positive power, a second lens having a negative power, and third and fourth lenses in the form of meniscus having a positive power, respectively; and a second lens group including a fifth lens having a positive power. Accordingly, the telecentric f-θ lens system has a flat image surface.

FIG. 3



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Telecentric f-θ Lens System

BACKGROUND OF THE INVENTION

Field of the Invention

The present invention relates to an f-θ lens system, and more particularly, it relates to a telecentric f-θ lens system which is applied to an optical beam scanner such as a laser printer.

Description of the Prior Art

An f-θ lens system satisfies:
$y = f \cdot \theta$
assuming that y represents the distance from an optical axis to a beam spot on an image formation surface to be scanned, f represents the focal length of the f-θ lens system and θ represents an angle of incidence of the beam upon the lens system. Therefore, when a laser beam is applied to a polygon mirror which is rotated at a constant angular velocity while imaging a beam reflected by the polygon mirror on an image formation surface through the f-θ lens system, the beam spot is moved on the image formation surface at a constant speed. In a conventional optical beam scanner, therefore, the polygon mirror is generally combined with the f-θ lens system in order to move the beam spot on the image formation surface at a constant speed.

Further, the conventional optical beam scanner employs a telecentric optical system in order to prevent from misregistration. This is because all principal rays substantially vertically enter an image formation surface in the telecentric optical system, to cause extremely small misregistration even if the image formation surface is displaced in the direction of an optical axis, for example, as is well known in the art.

Therefore, a telecentric f-θ lens system is employed in a laser printer etc. particularly requiring that a laser beam is incident upon the image formation surface in high accuracy. For example, Japanese Patent Laying-Open Gazettes Nos. 195211/1984 and 299927/1987 disclose telecentric f-θ lens systems of this type.

Fig. 1 illustrates the structure of a conventional telecentric f-θ lens system, which is disclosed in the former gazette (Japanese Patent Laying-Open Gazette No. 195211/1984). As shown in Fig. 1, the conventional telecentric f-θ lens system is formed by a negative lens L_{12} whose concave surface S_{12} directed toward an entrance pupil EP, positive meniscus lenses L_{13} and L_{14} and a positive plano-convex lens L_{15}, and these lenses L_{12} to L_{15} are arranged in order from the entrance pupil EP side toward an image formation surface IS side. Figs. 2A and 2B show spherical aberration and astigmatism of the telecentric f-θ lens system shown in Fig. 1, respectively.

A telecentric f-θ lens system disclosed in the latter gazette (Japanese Patent Laying-Open Gazette No. 299927/1987) is similar in structure to that shown in Fig. 1, except for that the f-θ lens system has been corrected for chromatic aberration.

In the conventional telecentric f-θ lens system having the aforementioned structure, the curve of the astigmatism is generally inclined toward the negative side as shown in Fig. 2B. In order to obtain a flat image surface, therefore, it is necessary to also incline the curve of the spherical aberration toward the negative side.

However, the curve of the spherical aberration is inclined toward the positive side in the conventional telecentric f-θ lens system, as shown in Fig. 2B. Thus, a flat image surface cannot be obtained in the conventional telecentric f-θ lens system.

Further, higher resolution is generally expected for an optical beam scanner. To this end, it is necessary to reduce in the diameter of a beam spot. Thus, the F-number must be minimized.

SUMMARY OF THE INVENTION

The present invention is directed to a telecentric f-θ lens system. The telecentric f-θ lens system comprises: (a) a first lens group having an entrance pupil, which includes (a-1) a first lens in the form of meniscus having a positive power whose concave surface is directed to the entrance pupil, (a-2) a second lens having a negative power, and (a-3) third and fourth lenses in the form of meniscus having a positive power, respectively; and (b) a second lens group including a fifth lens having a positive power. In the telecetric f-θ lens system, the first through fifth lenses are successively disposed in order from the entrance pupil side.

In an aspect of the present invention, the telecentric f-θ lens system satisfies following:

$-0.65 < (r_1/f) < -0.25$

$0.4 < (d_8/f) < 1.16$

$1.61 < (f_5/f) < 3.5$

where r_1 is a radius of curvature of the concave surface of the first lens; f is a focal length of the system; d_8 is a distance between the fourth and fifth lenses; and f_5 is a focal length of the fifth lens.

Further, the present invention is directed scanning system for scanning an optical beam on a recording surface, also. The scanning system comprises: a light source for generating an optical beam; a deflector for deflecting the optical beam outgoing from the light source; and a telecentric f-θ lens system for imaging the optical beam deflected by the deflector on the recording surface, within comprises: (a) a first lens group having an entrance pupil, which includes (a-1) a first lens in the form of meniscus having a positive power whose concave surface is directed to the entrance pupil, (a-2) a second lens having a negative power, and (a-3) third and fourth lenses in the form of meniscus having a positive power, respectively; and (b) a second lens group including a fifth lens having a positive power.

A principal object of the present invention is to provide a telecentric f-θ lens system which has an F-number of not more than 20, small spherical aberration, astigmatism and the like, and a flat image surface.

Another object of the present invention is to provide a scanning system which can scan an optical beam on a recording surface with high resolution.

These and other objects, features, aspects and advantages of the present invention will become more apparent from the following detailed description of the present invention when taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 illustrates the structure of a conventional telecentric f-θ lens system;

Figs. 2A and 2B illustrate spherical aberration and astigmatism of the conventional f-θ lens sytem shown in Fig. 1, respectively;

Fig. 3 illustrates an embodiment of a telecentric f-θ lens system according to the present invention;

Figs. 4A, 4B and 4C illustrate spherical aberration, astigmatism and f-θ characteristic of a first example, respectively;

Figs. 5A, 5B and 5C illustrate spherical aberration, astigmatism and f-θ characteristic of a second example, respectively;

Figs. 6A, 6B and 6C illustrate spherical aberration, astigmatism and f-θ characteristic of a third example, respectively;

Figs. 7A, 7B and 7C illustrate spherical aberration, astigmatism and f-θ characteristic of a fourth example, respectively;

Figs. 8A, 8B and 8C illustrate spherical aberration, astigmatism and f-θ characteristic of a fifth example, respectively;

Figs. 9A, 9B and 9C illustrate spherical aberration, astigmatism and f-θ characteristic of a sixth example, respectively;

Figs. 10A, 10B and 10C illustrate spherical aberration, astigmatism and f-θ characteristic of a seventh example, respectively;

Figs. 11A, 11B and 11C illustrate spherical aberration, astigmatism and f-θ characteristic of an eigth example, respectively; and

Fig. 12 is a perspective view showing an optical system of the optical beam scanner.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Fig. 3 illustrates an embodiment of a telecentric f-θ lens system according to the present invention. The f-θ lens system is formed by a rear lens group R_L and a front lens group F_L, which are arranged in order from an image formation surface IS side at a prescribed interval.

The front lens group F_L is formed by first, third and fourth meniscus lenses L_1, L_3 and L_4 having positive power and a second lens L_2 having negative power, as shown in Fig. 3. The first to fourth lenses L_1

to L_4 are arranged in order from an entrance pupil EP side at prescribed intervals, while all of concave surfaces S_1, S_3, S_5 and S_7 of the first to fourth lenses L_1 to L_4 are directed toward the entrance pupil EP.

On the other hand, the rear lens group R_L is formed by a fifth lens L_5 having positive power, and a convex surface S_{10} of the fifth lens L_5 is directed toward an image formation surface IS.

The f-θ lens system having the aforementioned structure satisfies:

$-0.65 < (r_1 \cdot f) < -0.25$ (1)

$0.4 < (d_8 \cdot f) < 1.16$ (2)

$1.61 < (f_5 \cdot f) < 3.5$ (3)

where r_1 represents the radius of curvature of a concave surface S_1 of the first lens L_1, d_8 represents the distance between the fourth and fifth lenses L_4 and L_5, f_5 represents the focal length of the fifth lens L_5, and f represents the focal length of the f-θ lens system.

The inequality (1) shows the condition for correcting the spherical aberration and curvature of image surface. That is, when the value (r_1/f) is not less than -0. 25, correction of the spherical aberration is so insufficient that the curve of astigmatism of the meridional image surface is also inclined toward the negative (-) side, whereby astigmatism at an end of a field angle is increased. When the value (r_1/f) is not more than -0.65, on the other hand, the spherical aberration is so excessively corrected and high-order meridional field curvature is increased.

Both the inequalities (2) and (3) show conditions that the f-θ lens system has a telecentric property. That is, when the value (d_8/f) is not more than 0.4, not only the f-θ lens system cannot have the telecentric property but high-order meridional field curvature is arised. When the value (d_8/f) is not less than 1.16, on the other hand, the spherical aberration is excessively corrected and both of the meridional and sagittal image surfaces tend to be inclined toward the negative (-) sides.

When the value (f_5/f) is not less than 3.5, both of the meridional and sagittal image surfaces are inclined toward the negative (-) sides, and when the value (f_5/f) is not more than 1.61, on the other hand, high-order astigmatism appears on the meridional image surface. In either case, therefore, it is difficult to implement a telecentric optical system which has small spherical aberration etc.

When, to the contrary, an f-θ lens is formed by the first to fifth lenses L_1 to L_5 and the f-θ lens satisfies the inequalities (1) to (3) (Examples 1 to 8 described below), a telecentric f-θ lens which has the following characteristics can be obtained:

(1) F-number is not more than 20;
(2) spherical aberration, astigmatism etc. are small; and
(3) image surface is flat.

Example 1

Table 1 shows lens data of a telecentric f-θ lens system structured along Fig. 3.

Table 1

i	r_i	d_i	n_i	γ_i
1	-63.355	2.10	1.78472	25.7
2	-39.601	8.68		
3	-21.347	1.00	1.51633	64.1
4	278.868	7.72		
5	-40.414	3.50	1.78472	25.7
6	-35.688	0.90		
7	-455.490	9.20	1.78472	25.7
8	-40.843	103.08		
9	∞	10.00	1.51633	64.1
10	-164.656			

Referring to Table 1, symbol r_i (i = 1, 2, ..., 10) represents radius of curvature of lens surfaces S_i, such that r_1 represents the radius of curvature of the concave surface S_1 of the first lens L_1 and r_2 represents the radius of curvature of the convex surface S_2 of the first lens L_1 directed toward the image formation surface IS. Symbol d_i (i = 1, 3, 5, 7, 9) represents thickness values of the first to fifth lenses L_1 to L_5, respectively. On the other hand, d_i (i = 2, 4, 6, 8) represents spaces between pairs of the first to fifth lenses L_1 to L_5, respectively, such that d_2 represents the space between the first and second lenses L_1 and L_2, for example. Symbol n_i (i = 1, 2, ..., 5) represents indexes of refraction of the first to fifth lenses L_1 to L_5 with respect to a line d. Symbol γ_i (i = 1, 2, ..., 5) represents Abbe's numbers of the first to fifth lenses L_1 to L_5.

The focal length f, the F-number F_{NO} etc. of the telecentric f-θ lens having the aforementioned lens data are set as hown in Table 2.

Table 2

f	F_{NO}	λ	d_0
100.00	20	623.8 mm	15.00

Referring to Table 2, d_0 represents the space between the entrance pupil EP and the concave surface S_1 of the first lens L_1. The focal length f_5 of the fifth lens L_5 is 320, although this is not shown in Tables 1 and 2.

Thus,

$r_1/f = -0.634$

$d_8/f = 1.031$

$f_5/f = 3.20$

and it is apparent that the telecentric f-θ lens system satisfies the inequalities (1) to (3).

Figs. 4A, 4B and 4C illustrate spherical aberration, astigmatism and f-θ characteristic of the telecentric f-θ lens system having the aforementioned structure, respectively. The results shown in these figures have been obtained with respect to light of 632.8 nm in wavelength on the basis of the above data.

In each of Fig. 4B and Figs. 5B, 6B, 7B, 8B, 9B, 10B and 11B, which are hereinafter described in detail, symbol S denotes a sagittal image surface and symbol M denotes a meridional image surface, respectively.

The f-θ characteristic shown in each of Figs. 4C, 5C, 6C, 7C, 8C, 9C, 10C and 11C is a value showing scanning property provided by the following definition assuming that θ represents an angle of polarization and y represents a beam spot position from an optical axis Z on an image formation surface:

$$\text{f-}\theta\ \text{characteristic} = \frac{y - f\cdot\theta}{f\cdot\theta}\cdot 100\ (\%) \qquad \ldots (4)$$

Example 2

Table 3 shows lens data of a second example according to the telecentric f-θ lens system.

Table 3

i	r_i	d_i	n_i	ν_i
1	-25.000	2.00	1.78472	25.7
2	-23.534	15.55		
3	-18.738	1.00	1.71736	29.5
4	-92.650	1.75		
5	-58.459	5.50	1.78472	25.7
6	-31.058	0.25		
7	-103.512	9.00	1.78472	25.7
8	-36.160	78.72		
9	∞	11.50	1.51633	64.1
10	-134.791			

The focal length f, the F-number F_{NO} etc. of the telecentric f-θ lens system having the aforementioned lens data are set as shown in Table 4.

Table 4

f	F_{NO}	λ	d_0
100.00	20	632.8 mm	15.00

The focal length f_5 of the fifth lens L_5 is 261.9, although this is not shown in Tables 3 and 4.

Thus,

$r_1/f = -0.25$
$d_8/f = 0.787$
$f_5/f = 2.619$

and it is apparent that the telecentric f-θ lens satisfies the inequalities (1) to (3).

Figs 5A, 5B and 5C illustrate spherical aberration, astigmatism and f-θ characteristic of the telecentric f-θ lens having the aforementioned structure, respectively. The results shown in these figures have been obtained with respect to light of 632.8 nm in wavelength on the basis of the above data.

Example 3

Table 5 shows lens data of a third example according to the telecentric f-θ lens system.

Table 5

i	r_i	d_i	n_i	ν_i
1	-49.574	2.70	1.78472	25.7
2	-23.680	3.40		
3	-17.325	1.00	1.51633	64.1
4	245.713	14.13		
5	-54.458	3.10	1.78472	25.7
6	-49.970	0.50		
7	-159.298	9.00	1.78472	25.7
8	-38.543	116.00		
9	∞	9.50	1.51633	64.1
10	-176.901			

The focal length f, the F-number F_{NO} etc. of the telecentric f-θ lens system having the aforementioned lens data are set as shown in Table 6.

Table 6

f	F_{NO}	λ	d_0
100.00	20	632.8 mm	15.00

The focal length f_5 of the fifth lens L_5 is 343.8, although this is not shown in Tables 5 and 6.

Thus,

$r_1/f = -0.469$

$d_8/f = 1.16$

$f_5/f = 3.438$

and it is apparent that the telecentric f-θ lens satisfies the inequalities (1) to (3).

Figs 6A, 6B and 6C illustrate spherical aberration, astigmatism and f-θ characteristic of the telecentric f-θ lens having the aforementioned structure, respectively. The results shown in these figures have been obtained with respect to light of 632.8 nm in wavelength on the basis of the above data.

Example 4

Table 7 shows lens data of a fourth example according to the telecentric f-θ lens system.

Table 7

i	r_i	d_i	n_i	ν_i
1	-40.018	2.00	1.71736	29.5
2	-30.385	11.33		
3	-20.391	1.00	1.78472	25.7
4	-112.974	2.46		
5	-35.100	4.20	1.71736	29.5
6	-28.594	3.70		
7	-102.502	9.50	1.71736	29.5
8	-38.179	40.00		
9	∞	14.50	1.51633	64.1
10	-83.148			

The focal length f, the F-number F_{NO} etc. of the telecentric f-θ lens system having the aforementioned lens data are set as shown in Table 8.

Table 8

f	F_{NO}	λ	d_0
100.00	20	632.8 mm	15.00

The focal length f_5 of the fifth lens L_5 is 161.6, although this is not shown in Tables 7 and 8.

Thus,

$r_1/f = -0.400$
$d_8/f = 0.400$
$f_5/f = 1.616$

and it is apparent that the telecentric f-θ lens satisfies the inequalities (1) to (3).

Figs 7A, 7B and 7C illustrate spherical aberration, astigmatism and f-θ characteristic of the telecentric f-θ lens having the aforementioned structure, respectively. The results shown in these figures have been obtained with respect to light of 632.8 nm in wavelength on the basis of the above data.

Example 5

Table 9 shows lens data of a fifth example according to the telecentric f-θ lens system.

Table 9

i	r_i	d_i	n_i	γ_i
1	-42.984	1.900	1.78472	25.7
2	-34.391	12.103		
3	-21.164	1.000	1.51633	64.1
4	-495.525	5.807		
5	-38.567	3.600	1.78472	25.7
6	-34.375	0.200		
7	-221.116	8.800	1.78472	25.7
8	-40.072	71.294		
9	∞	11.600	1.51633	64.1
10	-119.132			

The focal length f, the F-number F_{NO} etc. of the telecentric f-θ lens system having the aforementioned lens data are set as shown in Table 10.

Table 10

f	F_{NO}	λ	d_0
100.00	18.018	632.8 mm	15.00

The focal length f_5 of the fifth lens L_5 is 231.5, although this is not shown in Tables 9 and 10.

Thus,

$r_1/f = -0.430$

$d_8/f = 0.713$

$f_5/f = 2.315$

and it is apparent that the telecentric f-θ lens satisfies the inequalities (1) to (3).

Figs 8A, 8B and 8C illustrate spherical aberration, astigmatism and f-θ characteristic of the telecentric f-θ lens having the aforementioned structure, respectively. The results shown in these figures have been obtained with respect to light of 632.8 nm in wavelength on the basis of the above data.

Example 6

Table 11 shows lens data of a sixth example according to the telecentric f-θ lens system.

Table 11

i	r_i	d_i	n_i	ν_i
1	-37.850	1.000	1.78472	25.7
2	-29.207	8.660		
3	15.139	1.000	1.62004	36.3
4	-101.234	2.070		
5	-24.238	2.500	1.78472	25.7
6	-21.767	0.200		
7	-95.298	5.000	1.78472	25.7
8	-24.567	105.425		
9	∞	10.000	1.51633	64.1
10	-102.457			

The focal length f, the F-number F_{NO} etc. of the telecentric f-θ lens system having the aforementioned lens data are set as shown in Table 12.

Table 12

f	F_{NO}	λ	d_0
100.00	20.00	632.8 mm	10.00

The focal length f_5 of the fifth lens L_5 is 199.1, although this is not shown in Tables 11 and 12.

Thus,

$r_1/f = -0.379$

$d_8/f = 1.054$

$f_5.f = 1.991$

and it is apparent that the telecentric f-θ lens satisfies the inequalities (1) to (3).

Figs 9A, 9B and 9C illustrate spherical aberration, astigmatism and f-θ characteristic of the telecentric f-θ lens having the aforementioned structure, respectively. The results shown in these figures have been obtained with respect to light of 632.8 nm in wavelength on the basis of the above data.

Example 7

Table 13 shows lens data of a seventh example according to the telecentric f-θ lens system.

Table 13

i	r_i	d_i	n_i	ν_i
1	-34.951	2.00	1.78472	25.7
2	-29.415	10.34		
3	-16.813	1.00	1.51633	64.1
4	-106.737	1.97		
5	-28.750	3.00	1.78472	25.7
6	-25.467	0.50		
7	-94.188	7.00	1.78472	25.7
8	-29.691	96.14		
9	∞	12.00	1.51633	64.1
10	-108.194			

The focal length f, the F-number F_{NO} etc. of the telecentric f-θ lens system having the aforementioned lens data are set as shown in Table 14.

Table 14

f	F_{NO}	λ	d_0
100.00	18.018	632.8 mm	10.00

The focal length f_5 of the fifth lens L_5 is 210.2, although this is not shown in Tables 13 and 14.

Thus,

$r_1/f = -0.350$

$d_8/f = 0.961$

$f_5/f = 2.102$

and it is apparent that the telecentric f-θ lens satisfies the inequalities (1) to (3).

Figs 10A, 10B and 10C illustrate spherical aberration, astigmatism and f-θ characteristic of the telecentric f-θ lens having the aforementioned structure, respectively. The results shown in these figures have been obtained with respect to light of 632.8 nm in wavelength on the basis of the above data.

Example 8

Table 15 shows lens data of a seventh example according to the telecentric f-θ lens system.

Table 15

i	r_i	d_i	n_i	ν_i
1	-39.861	2.00	1.78472	25.7
2	-33.433	11.19		
3	-17.846	1.00	1.51633	64.1
4	-141.271	2.42		
5	-29.362	3.00	1.78472	25.7
6	-26.362	0.50		
7	-119.853	7.00	1.78472	25.7
8	-31.782	98.33		
9	∞	12.00	1.51633	64.1
10	-112.015			

The focal length f, the F-number F_{NO} etc. of the telecentric f-θ lens system having the aforementioned lens data are set as shown in Table 16.

Table 16

f	F_{NO}	λ	d_0
100.00	18.018	488 mm	10.00

The focal length f_5 of the fifth lens L_5 is 214.7, although this is not shown in Tables 15 and 16.

Thus,

$r_1/f = -0.399$

$d_8/f = 0.983$

$f_5/f = 2.147$

and it is apparent that the telecentric f-θ lens satisfies the inequalities (1) to (3).

Figs 11A, 11B and 11C illustrate spherical aberration, astigmatism and f-θ characteristic of the telecentric f-θ lens having the aforementioned structure, respectively. The results shown in these figures have been obtained with respect to light of 488 nm in wavelength on the basis of the above data.

The spherical aberration of the f-θ lens system is extremely small as understood from the spherical aberration diagrams (Figs. 4A, 5A, 6A, 7A, 8A, 9A, 10A and 11A), and the astigmatism thereof is also extremely small as understood from the astigmatism diagrams (Figs. 4B, 5B, 6B, 7B, 8B, 9B, 10B and 11B). Further, the f-θ lens system structured as above has an excellent f-θ characteristic, as understood from the f-θ characteristic diagrams (Figs. 4C, 5C, 6C, 7C, 8C, 9C, 10C and 11C).

As shown in the spherical aberration diagrams and the astigmatism diagrams, the curves of the spherical aberration and astigmatism of the f-θ lens system are inclined toward the same direction. In Example 6, for example, the curve of the spherical aberration is inclined toward the negative side (see Fig. 9A), while the curve of the astigmatism is also inclined toward the negative side (see Fig. 9B). Thus, a flat image surface can be obtained, which is formed by putting together with least circles of confusion.

Further, all the F-numbers F_{NO} of the f-θ lens systems are not more than 20 in Examples 1 to 8, as hereinabove described. Therefore, when the aforementioned f-θ lens is applied to an optical beam scanner shown in Fig. 12, the beam spot diameter can be easily reduced to thereby improve resolution of the scanner.

Fig. 12 is a perspective view showing an optical system of the optical beam scanner to which the aforementioned telecentric f-θ lens system is applied. Referring to Fig. 12, a laser beam B_1 outgoing from a laser tube 21 is incident upon an optical modulator system 25 which is formed by lenses 22 and 23 and an acoustic optical modulation element 24. In the optical modulator system 25, the beam B_1 enters the lens 22 at a prescribed angle to an optical axis of the lens 22 to be inclined by a prescribed angle from the horizontal plane (X-Y plane), so that a laser beam B_2 then enters the acoustic optical modulation element 24. This laser beam B_2 is on-off controlled on the basis of a signal which corresponds to an image to be recorded on a drum 30, which will be hereinafter described in detail. A laser beam B_3 outgoing from the acoustic optical modulation element 24 with inclination from the horizontal plane (X-Y plane) is corrected to a horizontal laser beam B_4 by the lens 23.

The laser beam B_4 reflected by a mirror 26, and thereafter incident upon a polygon mirror 28 which is rotated at a constant angular velocity through a beam expander 27. Since a diameter of a laser beam B_5 reflected by the polygon mirror 28 is varied according to an area of the reflecting surface thereof, the polygon mirror 28 performs not only a deflector but also an apperture stop, so that an entrance pupil of a telecentric f-θ lens system 29, which is structed along Fig. 3, is located on the reflecting surface of the polygon mirror 28. The laser beam B_5 reflected by the polygon mirror 28 is imaged on the drum 30 through the telecentric f-θ lens system 29. Therefore, a laser beam B_6 applied onto the drum 30 through the polygon mirror 28 and the telecentric f-θ lens system 29 performs scanning in a direction parallel to the axis 30a of rotation of the drum 30, i.e., the so-called primary scanning direction X.

The drum 30 is coupled with a driving part (not shown) to be rotated about the rotation axis 30a by the driving part for subscanning.

As hereinabove described, the above telecentric f-θ lens system 29 having a small F-number can be applied to the optical system of the optical beam scanner shown in Fig. 12, whereby the beam spot diameter of the laser beam B_6 can be easily reduced to improve resolution of the optical beam scanner.

Although the present invention has been described and illustrated in detail, it is clearly understood that the same is by way of illustration and example only and is not to be taken by way of limitation. The spirit and scope of the present invention should be limited only by the terms of the appended claims.

The features disclosed in the foregoing description, in the claims and/or in the accompanying drawings may, both, separately and in any combination thereof, be material for realising the invention in diverse forms thereof.

Claims

1. A telecentric f-θ lens system comprising:

(a) a first lens group (FL) having an entrance pupil (EP), characterised in that the first lens group includes:
(a-1) a first meniscus lens (L_1) having a positive power, said first lens (L_1) having a concave surface (S_1) which is directed towards said entrance pupil (EP),
(a-2) a second lens (L_2) having a negative power,
(a-3) third and fourth meniscus lenses (L_3,L_4) each having a positive power, respectively; and

(b) a second lens group (RL) including a fifth lens (L_5) having a positive power, said first through fifth lenses (L_1-L_5) being successively disposed in order from said entrance pupil (EP).

2. A telecentric f-θ lens system according to Claim 1, wherein said telecentric f-θ lens system satisfies the following:
$-0.65 < (r_1/f) < -0.25$
$0.4 < (d_8/f) < 1.16$
$1.61 < (f_5/f) < 3.5$
where r_1 the radius of curvature of said concave surface (S_1) of said first lens (L_1); f is the focal length of the system; d_8 is the distance between said fourth and fifth lenses (L_4, L_5); and f_5 is the focal length of said fifth lens (L_5).

3. A scanning system for scanning an optical beam (B) on a recording surface (30), said scanning system comprising:
a light source (21) for generating an optical beam (B) and
a deflector (28) for deflecting the optical beam (B) outgoing from said light source (21) and characterised in

that the scanning system further comprises:
a telecentric f-θ lens system (29) for imaging the optical beam (B) deflected by said deflector (28) on said recording surface (30), said telecentric f-0 lens system (29) comprising: (a) a first lens group (FL) having an entrance pupil (EP), which includes (a-1) a first meniscus lens (L_1) having a positive power, said first lens having a concave surface (S_1) which is directed to said entrance pupil (EP), (a-2) a second lens (L_2) having a negative power, and (a-3) third and fourth meniscus lenses (L_3, L_4) having a positive power, respectively; and (b) a second lens group (RL) including a fifth lens (L_5) having a positive power, said first through fifth lenses (L_1, L_5) being successfully disposed in order from said entrance pupil (EP) side.

4. A scanning system according to Claim 3, wherein said telecentric f-θ lens system satisfies the following:
$-0.65<(r_1/f)<-0.25$
$0.4 < (d_8/f) < 1.16$
$1.61 < (f_5/f) < 3.5$
where r_1 is the radius of curvature of said concave surface (S_1) of said first lens (L_1); f is the focal length of the system; d_8 is the distance between said fourth and fifth lenses (L_4, L_5); and f_5 is the focal length of said fifth lens (L_5).

FIG. 1

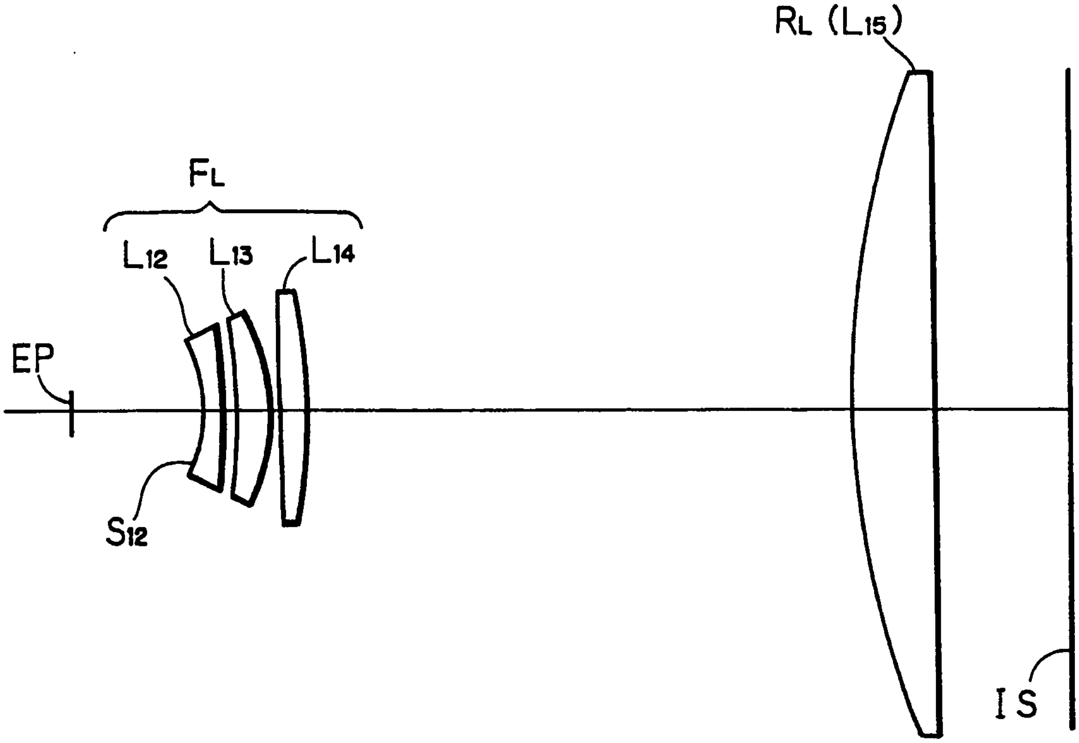


FIG. 2A

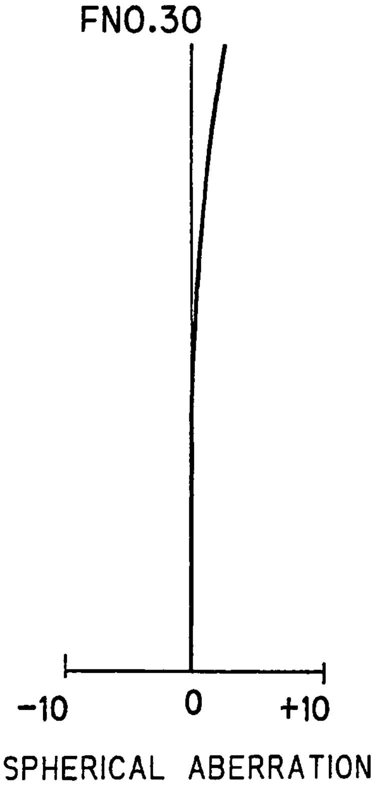


FIG. 2B

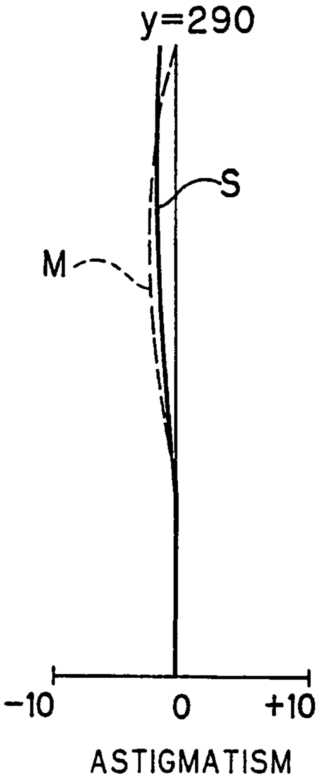


FIG. 3

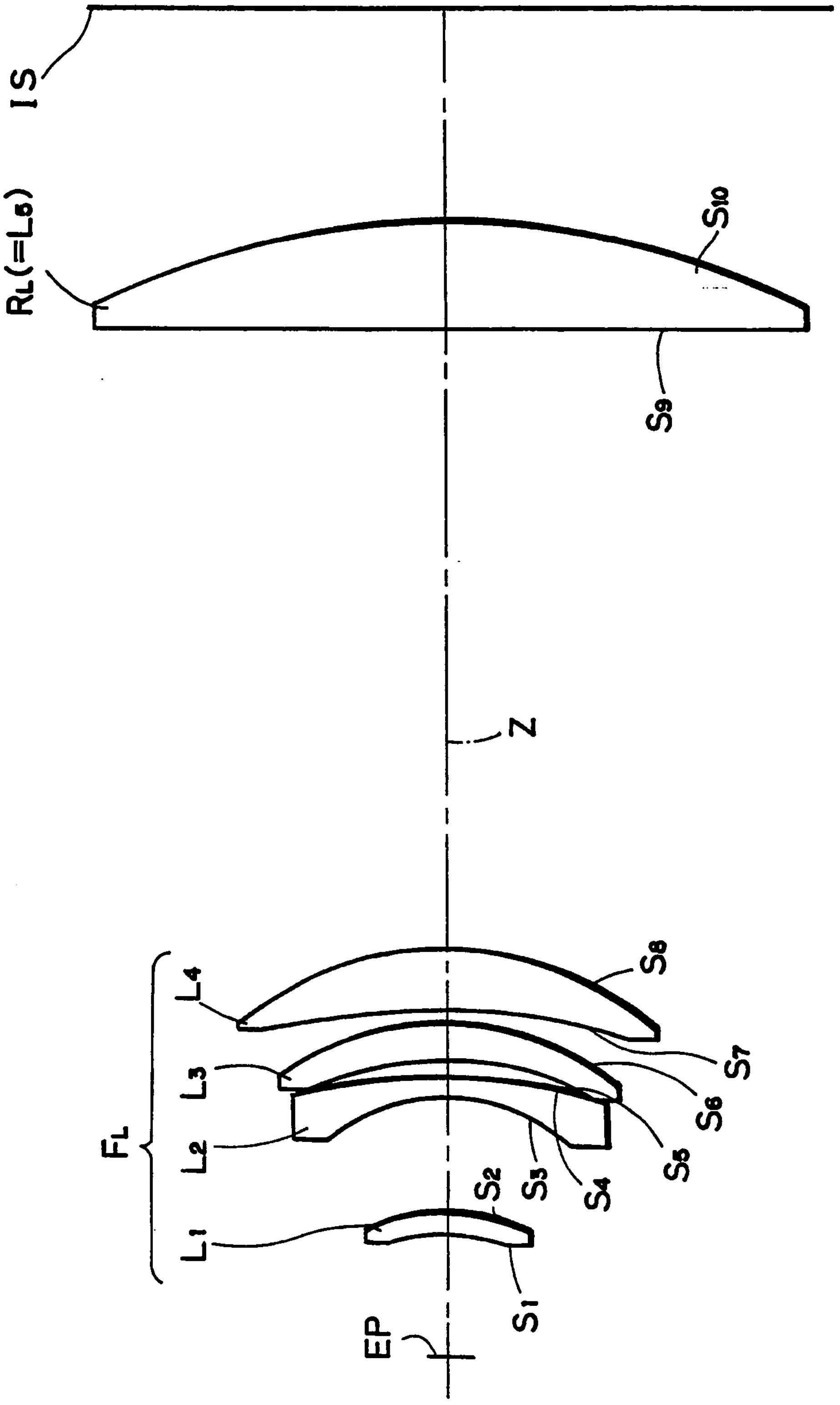


FIG. 4A

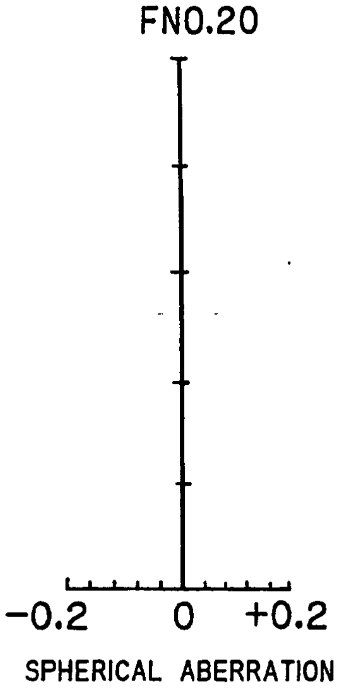


FIG. 4B

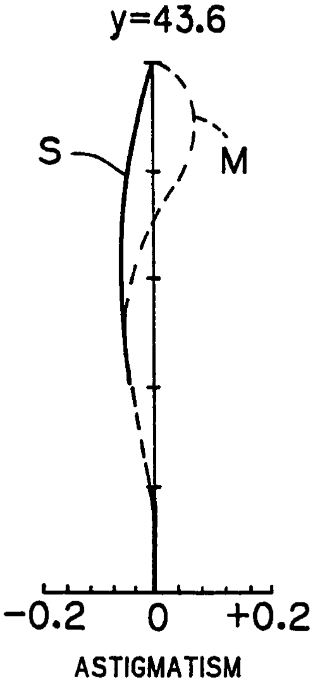


FIG. 4C

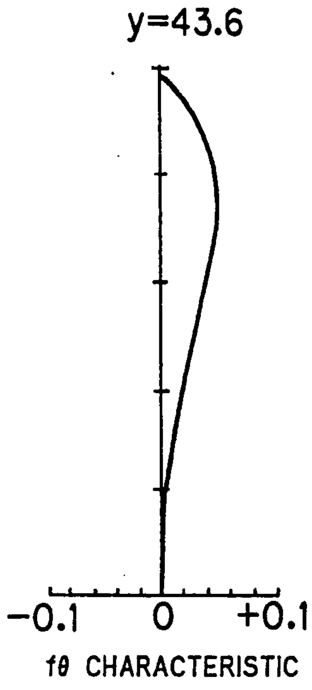


FIG. 5A

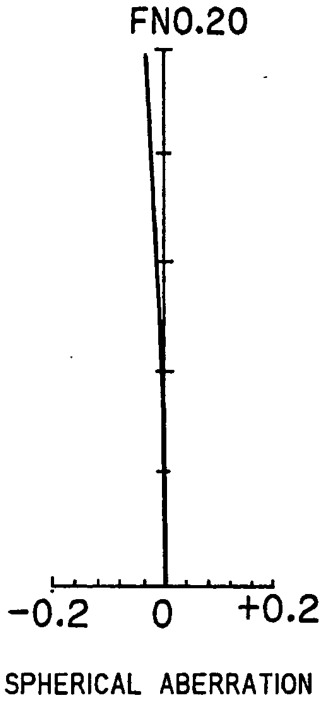


FIG. 5B

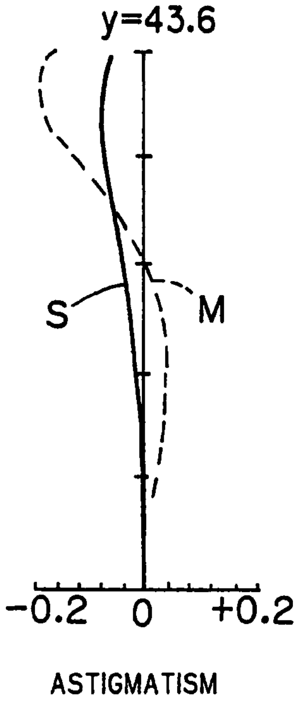


FIG. 5C

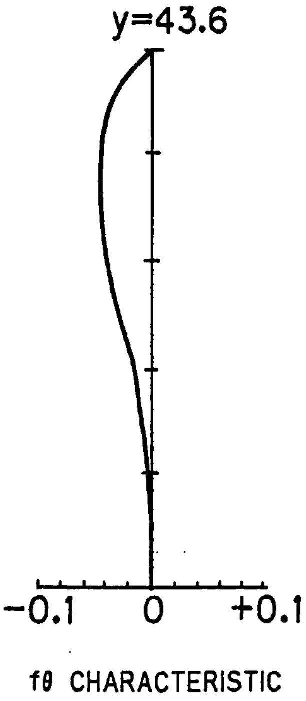


FIG.6A

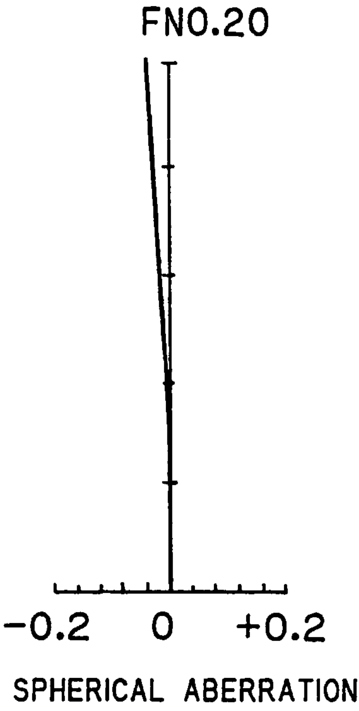


FIG.6B

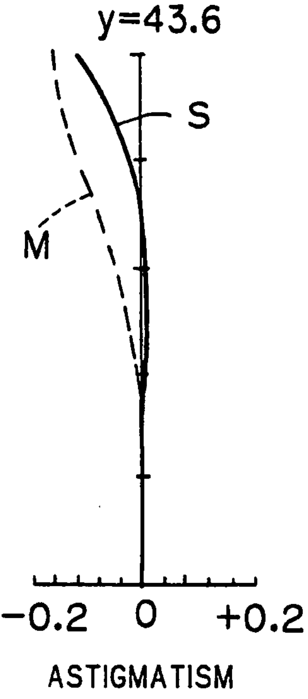


FIG.6C

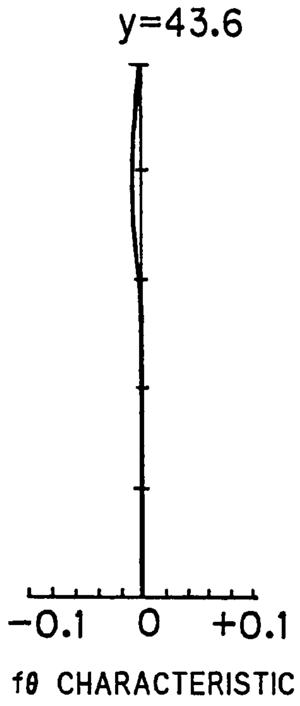


FIG.7A

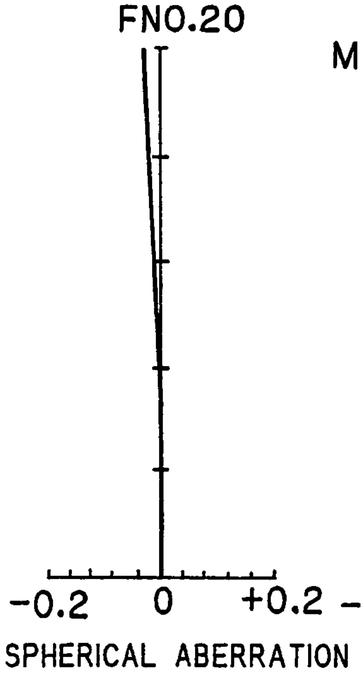


FIG.7B

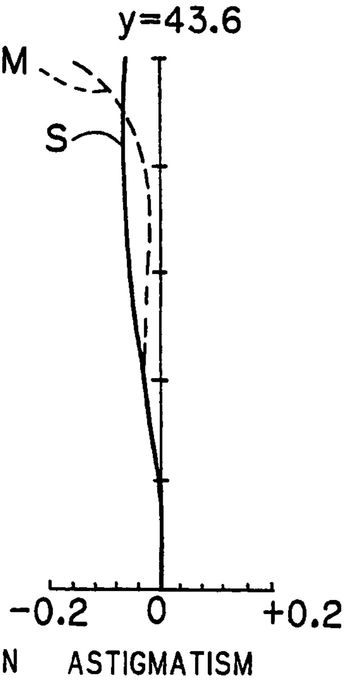


FIG.7C

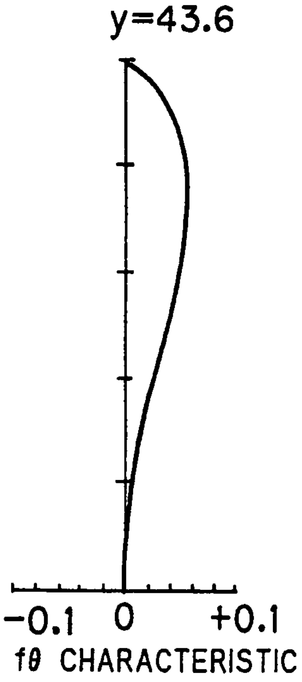
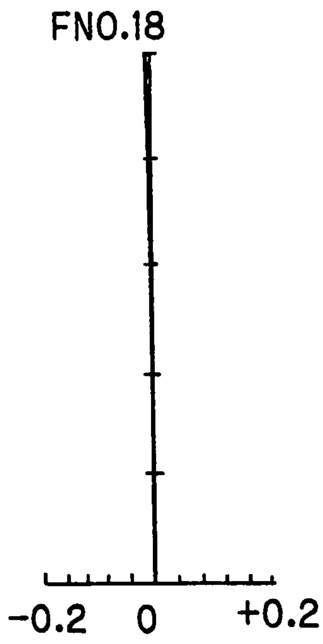
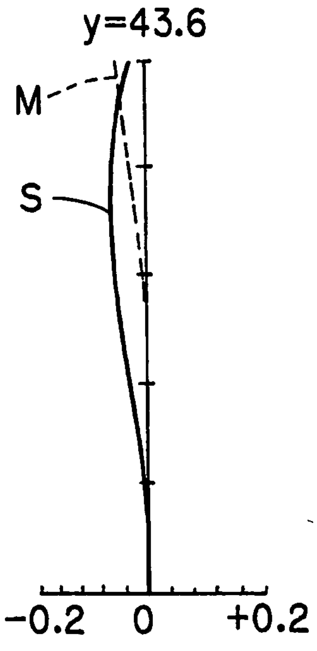


FIG.8A



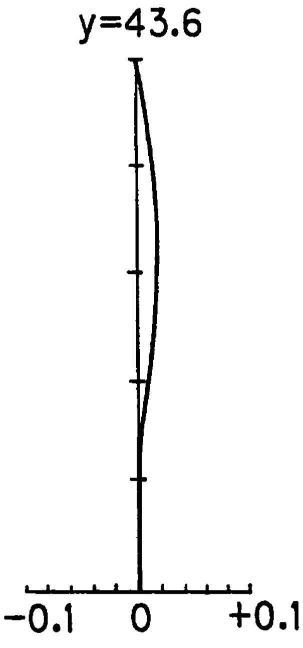
SPHERICAL ABERRATION

FIG.8B



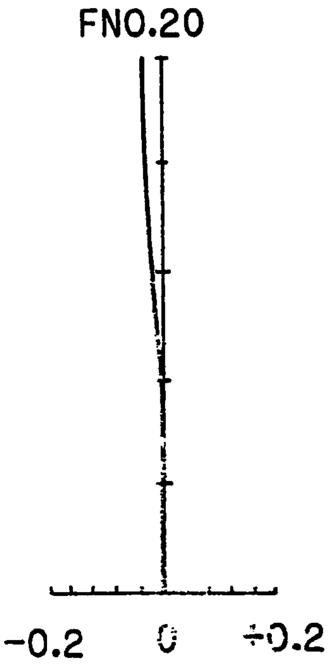
ASTIGMATISM

FIG.8C



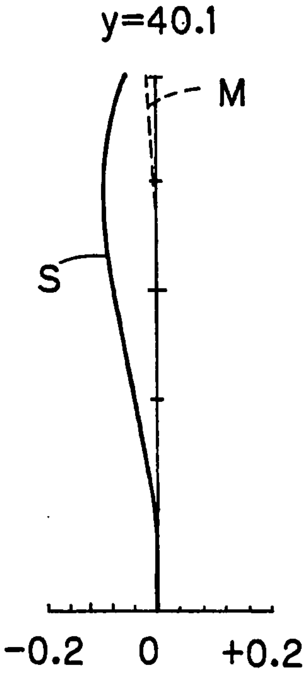
fθ CHARACTERISTIC

FIG.9A



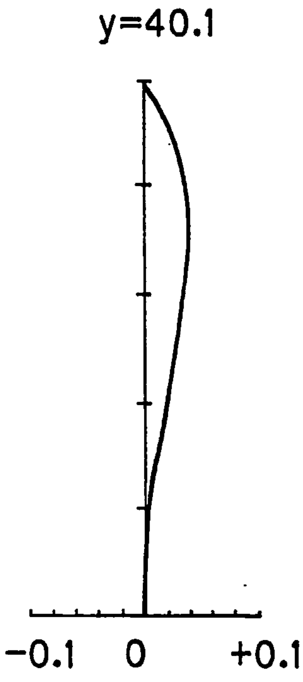
SPHERICAL ABERRATION

FIG.9B



ASTIGMATISM

FIG.9C



fθ CHARACTERISTIC

FIG. 10A

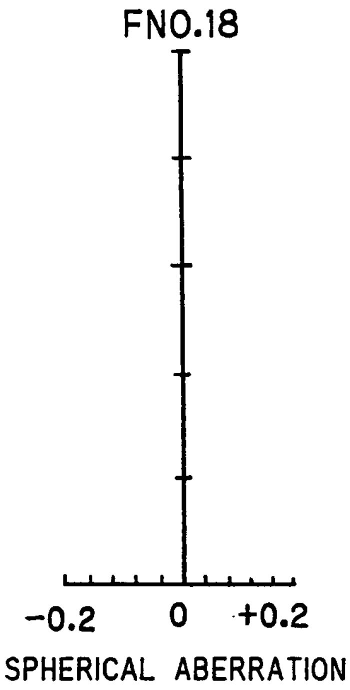


FIG. 10B

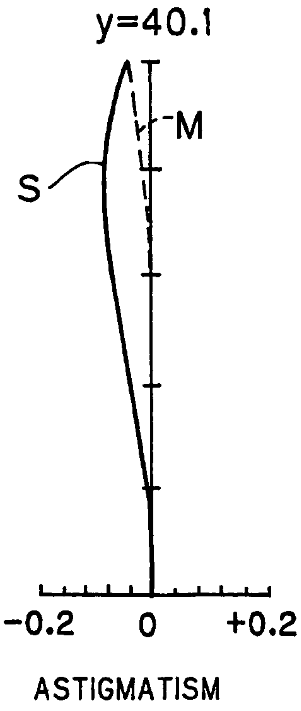


FIG. 10C

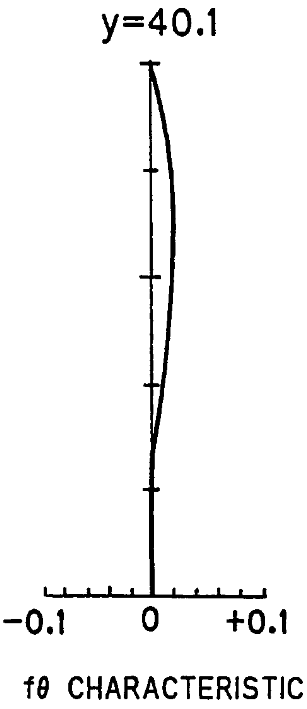


FIG. 11A

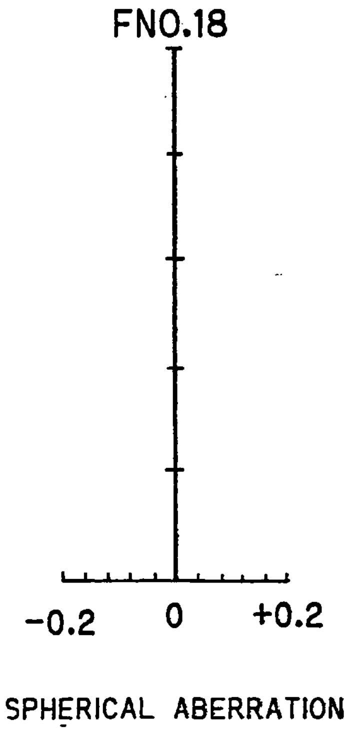


FIG. 11B

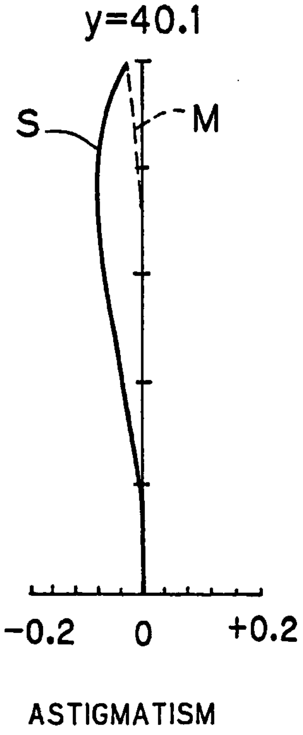


FIG. 11C

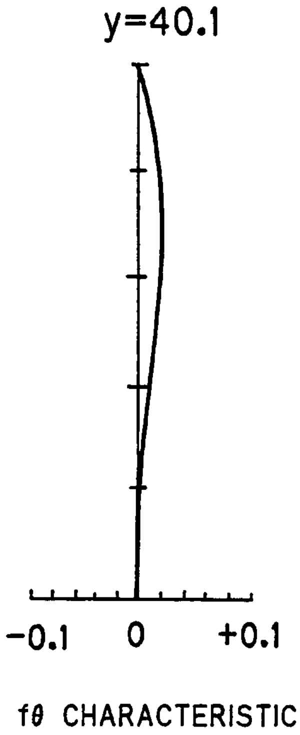


FIG. 12